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Resistively Heated Catalytic Converter with Air Injection for Oxidation of Carbon Monoxide and Hydrocarbons at Reduced Ambient Temperatures

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16. ABSTRACT

A resistively-heated metal monolith catalytic converter together with a belt-driven air pump was evaluated on a gasoline-fueled vehicle. The purpose of this work was the evaluation of this system on a gasoline-fuled light-duty vehicle over the Federal test procedure (FTP) cycle at 20 F ambient conditions. Description of the test program, vehicle description, test facilities and analytical methods, testing results and future efforts are included.

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Technical Report

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by

Gregory K. Piotrowski

September 1989

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Light-duty automotive emissions of CO are of particular concern to the U.S. EPA. The National Ambient Air Quality Standards (NAAQS) for CO are 10 mg/m^3 (9 ppm) over 8 hours, and 40 mg/m^3 (35 ppm) over a 1-hour time period.[7] During 1987, 59 cities or metropolitan areas exceeded the CO standards on one or more days.[8] These metropolitan regions represented a population of over 86 million people. It has been observed that 90 percent of these violations occurred on days when the ambient temperature dropped below the 68°F floor specified in the transient driving requirements in certification regulations.[9] An earlier study [10] also noted that 83 percent of the exceedances of the NAAQS for CO had been occurring outside of the temperature range of 68°F to 86°F at that time.

The relative importance of increases in Bag 1 CO emissions to weighted FTP averages due to colder ambient conditions has been demonstrated by the U.S. EPA. A small fleet of in-use vehicles was tested over the FTP cycle at 75°F, 50°F, and 20°F ambient conditions.[8] Bag 1 CO levels increased 529 percent from 75°F levels when the vehicles were tested at 20°F. Similar increases in CO over the Bag 1 portion of the FTP were noted in earlier EPA studies.[6,11] The stabilized and hot transient portions of the FTP show increases in CO at lower ambient temperatures; these increases, as a fraction of 20°F test levels versus 75°F test levels are less than half of those determined from Bag 1 testing. Bag 1 CO emission levels are also comparatively much higher than CO from the stabilized and hot transient portions of the FTP at 75°F and lower ambient conditions.[6,8,11]

Higher Bag 1 CO emissions at lower ambient temperatures may be caused by several factors. First, drivetrain friction is greater at colder temperature. An engine therefore must convert more energy to obtain similar acceleration and constant speed at lower ambients until the difference in frictional resistance between 75°F and the colder ambient conditions is overcome. Fuel distribution, wall wetting, etc. may become problems of greater concern as ambient temperature decreases because of increasingly poorer fuel atomization. An increased period of fuel enrichment may be necessary to overcome driveability problems caused by poorer fuel distribution and inefficient combustion at lower temperatures. Catalytic converters also may take longer to "light-off," or come to effective operating temperature at lower ambients.

A resistively heated metal monolith catalyst has been evaluated on both methanol and gasoline-fueled vehicles [12,13,14]. Camet Inc., a subsidiary of W.R. Grace, provided this catalyst for our evaluation. This catalyst can be heated to a temperature of 1000°F in a very short period of time prior

The use of resistive heating and the simultaneous addition of excess air appeared to cause a slight reduction in emissions of CO. When air at 2.4 SCFM was added during catalyst heating/engine operation CO emissions fell to 175.6 grams over Bag 1; this compares to 190.5 grams for the no heat/no air configuration. This represents an almost 9 percent increase in CO efficiency over Bag 1. Weighted FTP efficiencies increased over 7 percent for CO through the use of this heating/air addition strategy.

Increasing the amount of time the catalyst was resistively heated during Bag 1 while adding air at 2.4 SCFM during the simultaneous heating/engine-running period was then evaluated. The Bag 1 preheat time was kept at 10 seconds; the time that the catalyst was resistively heated after cold start was increased to 50 seconds, an increase from the 30-second post-start heating time of the previous configuration.

The increased heating period did not lower CO emissions below levels from the previously tested configuration. CO weighted FTP average emissions were essentially unchanged from levels with the catalyst in the no-heat/no-air mode. CO emissions over Bags 1 and 3 were also unchanged from levels measured with the no-heat/no-air configuration.

CO by percent in undiluted exhaust (ahead of the CVS) was continuously monitored during the Bag 1 portion of the tests, which utilized the 10/50 heating scheme and addition of air over the catalyst at 2.4 SCFM. CO was measured at 9 percent of undiluted exhaust during the first 3 minutes of Bag 1 at 20°F ambient conditions. CO concentration dropped sharply during the period of 180 to 240 seconds into a test; after approximately 4 minutes of engine operation, CO had fallen to a stable value much less than 1 percent. The level did not change after that time. Any reduction of CO during this 3-4 minute period could substantially reduce weighted FTP CO emissions.

The goal of the testing described here was to lower emissions of CO and HC over the first 3-4 minutes of the FTP cycle at 20°F ambient conditions. This was to be accomplished by resistively heating the catalytic converter and through the use of air added in front of the catalyst in conjunction with the resistive heating. The catalyst would be resistively heated for a longer period of time than in the configurations previously tested; [13] air would be added in front of the catalyst with a belt-driven air pump, rather than from a bottle of compressed air.

Table 1

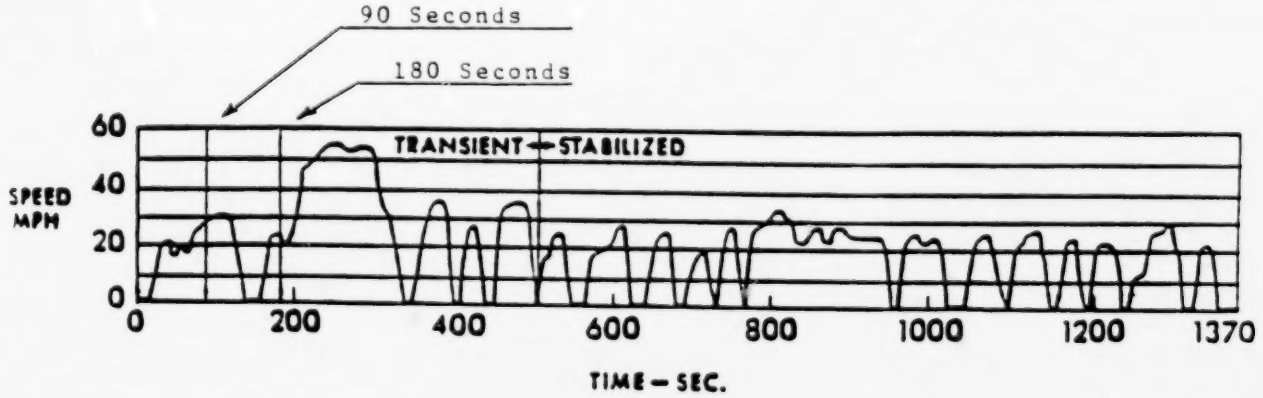
Catalyst Resistive Heating/Air-Addition Schemes
Catalyst As Originally Supplied

Catalyst Configuration	Resistive Heating	Excess Air Supplied
Baseline	None	None
Number 1	10/50, Bag 1*	None
Number 2	None	3 minutes, Bag 1**
Number 3	10/80, Bag 1	3 minutes, Bag 1
Number 4	10/170, Bag 1	3 minutes, Bag 1

* Signifies heating for 10 seconds prior to vehicle start, 50 seconds following vehicle start.

** Signifies addition of air during the 3 minutes of Bag 1 immediately following cold start.

Figure 1
Driving Trace, Bags 1 And 2 Of The FTP Cycle



1. Determine the period of the FTP cycle of interest as the time period during which "excess" CO emissions are produced from the test vehicle.

2. Calculate how much additional air must be added over the catalyst to completely oxidize excess CO (and HC) emissions. Express this requirement as a flowrate.

3. Determine the range of engine speeds over the period of interest. By weighting engine speeds against time, estimate an average engine speed over the time period of interest.

4. Map the output of the air pump as a function of engine speed and diverter valve setting.

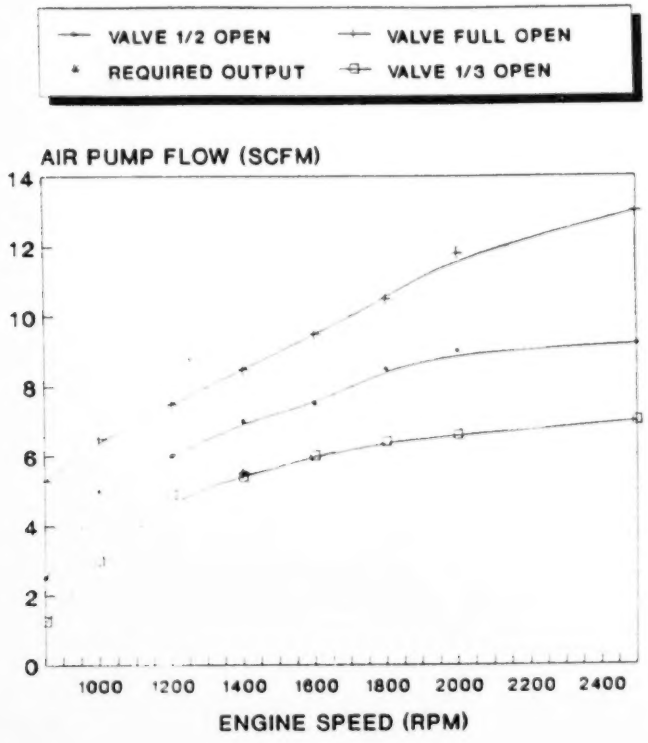
5. Choose the diverter valve setting which provides the calculated air flowrate at the average engine speed determined above.

The period of higher CO emissions in Bag 1 was determined in a qualitative manner. The difference in CO emission levels between Bag 1 and 3 of the FTP from the test vehicle at 20°F was assumed to be related to cold start. Therefore, the "excess" CO emissions of interest to us could be expressed as the difference between Bag 1 and 3 levels. The same assumption was made concerning HC emissions. Tailpipe CO emissions from the test vehicle over Bag 1 at 20°F were then continuously sampled using a Sun Emissions Analyzer. CO concentrations were very high at cold start; after approximately 3.2-4.0 minutes of driving the Bag 1 cycle, however, the concentration had declined in a step-change manner. The concentrations measured after this step-change varied only slightly during the remainder of Bag 1; this behavior was noted on several tests. We attributed the step-change reduction in emissions to catalyst light-off, and defined the first 3.2 minutes of Bag 1 as the period of high CO production for the test vehicle.

Because our air pump was belt driven, its output was a function of engine speed. The vehicle was run over Bag 1 of the FTP with continuously measured engine speed. A rough measure of engine speed versus time interval over the 3.2-minute period of interest was made, and an average engine speed of 1,413 rpm was determined.

The excess CO and HC emissions were assumed to occur during the first 3.2 minutes of Bag 1. Using an empirical ratio of CH 1:1.85 for HC, an additional air requirement of 5.4 SCFM was calculated. Stoichiometric conversion of CO and HC was postulated; any cooling effect on the catalyst caused by the addition of air was therefore minimized.

FIGURE 2
CAMET CATALYST EVALUATION
AIR PUMP CALIBRATION



Resistively heating the catalyst was next attempted with the simultaneous addition of air from the air pump. Resistive heating was applied at 10 seconds prior to cold start and continued for 80 seconds following cold start. Air was admitted in front of the catalyst immediately following cold start; air addition continued for 3 minutes.

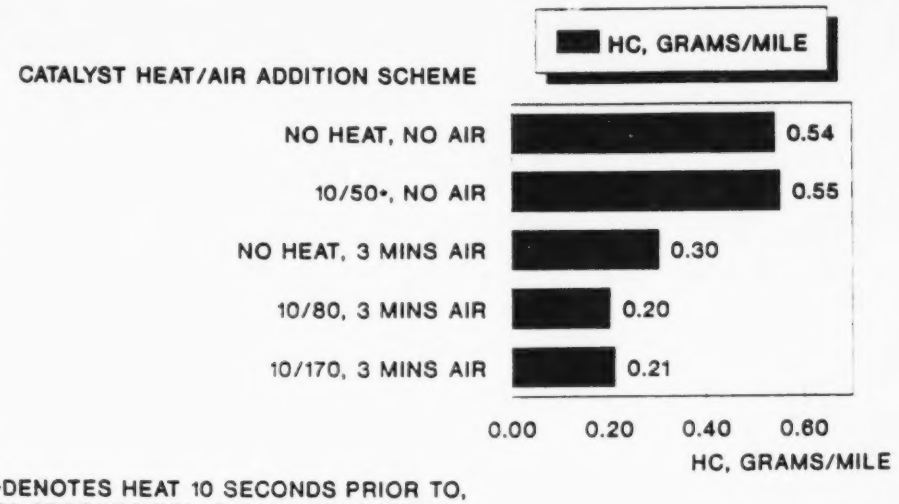
The combination of resistive heating and air addition provided a substantial improvement in CO emissions over the use of air addition alone. Bag 1 CO emissions were reduced to 63.5 grams, an almost 70 percent decrease in emissions from no-heat/no-air levels. This was also an almost 40 percent improvement over emission levels from the configuration which employed the addition of air for 3 minutes and no resistive heating.

The improvement in Bag 1 emissions translates into a substantial improvement in weighted FTP CO emissions. Average FTP CO emissions for this heated-catalyst/air-addition configuration were 3.9 grams per mile, close to the current light-duty car standard. The importance of Bag 1 emissions to weighted FTP emissions is again evident because this 3.9 grams per mile represents a 70 percent improvement from no-heat/no-air configuration levels, the same improvement realized in Bag 1 emissions.

Extending the period of catalyst resistive heating while leaving other variables unchanged did not appear to improve CO emission levels. The period of catalyst heating was increased to 3 minutes, approximately the time period relating to the production of significant quantities of CO mentioned previously. CO emissions were slightly higher in Bag 1 than those experienced with heating for 90 seconds only. Only two tests were conducted with the heating period extended to a full 3 minutes, however. The data from this limited amount of testing did not indicate that an improvement in CO emission levels would occur by merely extending the period of resistive heating beyond 90 seconds.

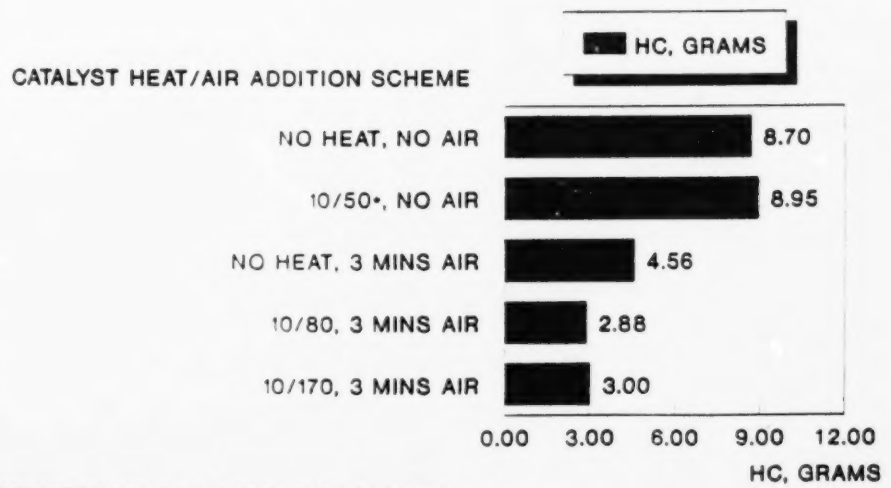
We are unable to account for the increase in CO emissions that occurred when the heating period was extended to 3 minutes. It was expected that emissions would have remained at the same level or decreased when the heating period was extended. This phenomena could be related to the part of the driving cycle covered by the additional resistive heating; a sharp decelleration and short idle period are included in this extended period of heating. This would not have been an expected result, however. The resistive heating/air addition schemes have not yet been optimized for this lower ambient temperature application; more work must be done to determine the cause of this phenomena.

FIGURE 5
HC, AVERAGE FTP
20 DEG. F AMBIENT CONDITIONS



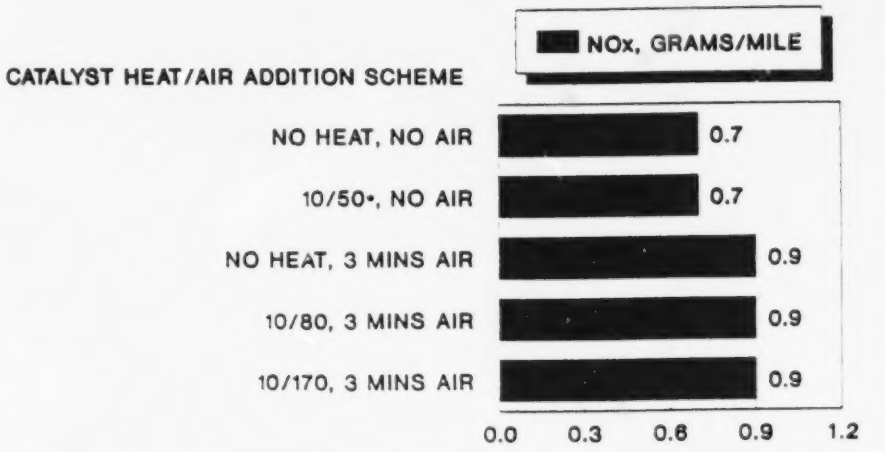
•DENOTES HEAT 10 SECONDS PRIOR TO,
50 SECONDS FOLLOWING COLD START

FIGURE 6
HC, BAG 1 OF FTP
20 DEG. F AMBIENT CONDITIONS



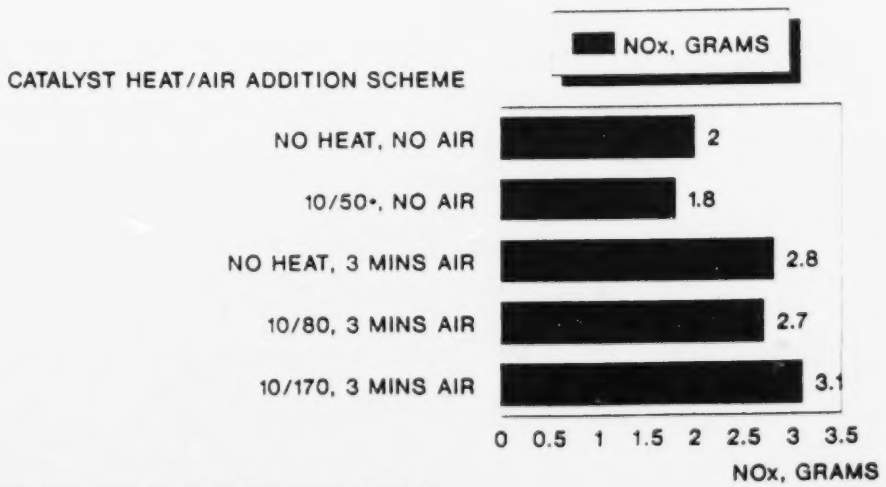
•DENOTES HEAT 10 SECONDS PRIOR TO,
50 SECONDS FOLLOWING COLD START

FIGURE 7
NOx, AVERAGE FTP
20 DEG. F AMBIENT CONDITIONS



•DENOTES HEAT 10 SECONDS PRIOR TO,
50 SECONDS FOLLOWING COLD START

FIGURE 8
NOx, BAG 1 OF FTP
20 DEG. F AMBIENT CONDITIONS



•DENOTES HEAT 10 SECONDS PRIOR TO,
50 SECONDS FOLLOWING COLD START

VIII. Future Effort

We are currently evaluating this resistively heated substrate with two different catalysts (palladium-only, and a base-metal configuration) for use as light-duty methanol vehicle catalysts. This work is being conducted at 72°F ambient conditions and will be the subject of a future EPA technical report.

Future efforts may utilize catalysts better suited to take advantage of the substrate's resistive heating characteristic. For example, an optimized system for low temperature CO control may require an oxidation catalyst rather than a three-way catalyst. The position of the converter in the exhaust stream is another factor which may be addressed in a future effort. We placed the resistively-heated catalyst in the same underfloor location as the stock converter in order to compare test results [12, 13]. The underfloor location used may not be the most desirable location in the exhaust stream for the converter if the design is tailored to a specific application, such as low temperature CO control.

The use of a two-catalyst system for specific applications may also be evaluated. A resistively heated substrate catalyzed specifically for formaldehyde control might be used with a second catalyst for optimal control of a variety of emissions from a methanol-fueled vehicle. A thermostatically controlled bypass valve might also be incorporated into this system.

The air addition strategy used in this work was simplified to facilitate project completion in a minimum amount of time. The optimum air strategy for low temperature CO oxidation was therefore probably not determined here. Future work may involve refinement of the air addition strategy for lower temperature CO control.

IX. Acknowledgements

The catalyst used in this test program was supplied by Camet, located in Hiram, OH. Camet is a manufacturer and sales agent for W. R. Grace and Company. The test vehicle used in this program was supplied by Volkswagen of America.

The author thanks James Garvey and Rodney Branham of the Test and Evaluation Branch (TEB), Emission Control Technology Division (ECTD), who conducted the driving cycle tests. The author also recognizes the efforts of Jennifer Criss of CTAB for typing and formating this report.

X. References (cont'd)

14. "Resistive Materials Applied To Quick Light-Off Catalysts," Hellman, K. H., et al., SAE Paper 890799, March 1989.

15. "The General Motors Air Injection Reactor Air Pump," Thompson, W. B., SAE Paper 660108, January 1966.

16. "Overview of the Clean Air Act Amendments of 1989," White House Summary Statement, reprinted in Inside EPA Weekly Report, July 28, 1989.

APPENDIX B

INDIVIDUAL FTP RESULTS

Table B-1 (cont'd)

Camet Catalyst - 20°F Ambient Conditions
Individual FTP Results

Test Number/Type	HC (g/mi)	CO (g/mi)	CO2 (g/mi)	NOx (g/mi)
893852/heat 10/80 Bag 1, 3 minutes air Bag 1	0.20	3.49	370.	1.05
893847/heat 10/80 Bag 1, 3 minutes air Bag 1	0.16	3.71	397.	1.10
894261/heat 10/170 Bag 1, 3 minutes air Bag 1	0.22	3.98	381.	0.89
894169/heat 10/170 Bag 1, 3 minutes air Bag 1	0.21	5.15	369.	0.91

Table C-1

Camet Catalyst - 20°F Ambient Conditions
Bag 1/Bag 3 Emission Levels Over The FTP Cycle

Test Number/Type	HC gms/gms	CO gms/gms	CO2 gms/gms	NOx gms/gms
892792/no heat, no air	8.39/0.22	199.74/1.09	1366/1186	1.07/1.70
892810/no heat, no air	9.46/0.22	222.62/1.22	1534/1223	1.55/1.63
893132/no heat, no air	8.30/0.20	215.05/1.22	1376/1183	2.26/2.56
894564/no heat, no air	8.66/0.30	166.80/2.03	1416/1204	3.19/2.79
892854/heat 10/50 Bag 1, 5/20 Bag 3 no air	8.96/0.20	194.14/0.82	1379/1169	1.65/1.92
893128/heat 10/50 Bag 1, 5/20 Bag 3 no air	8.94/0.18	227.40/1.08	1398/1197	1.87/1.93
892853/no heat, 3 minutes air Bag 1	4.14/0.23	100.00/1.01	1496/1158	1.71/2.34
893133/no heat, 3 minutes air Bag 1	5.14/0.25	107.83/1.50	1536/1227	2.99/2.57
893850/no heat, 3 minutes air Bag 1	4.39/0.23	108.01/1.90	1606/1269	3.57/2.89
892811/heat 10/80 Bag 1, 3 minutes air Bag 1	2.92/0.22	58.76/1.21	1589/1175	1.77/1.75
892812/heat 10/80 Bag 1, 3 minutes air Bag 1	3.08/0.20	67.24/0.92	1617/1182	1.83/1.74
893129/heat 10/80 Bag 1, 3 minutes air Bag 1	3.27/0.19	66.61/1.11	1576/1200	2.05/1.80
893130/heat 10/80 Bag 1, 3 minutes air Bag 1	2.92/0.22	69.98/0.90	1501/1176	2.28/2.16